Categorical color coding in goldfish

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Goldfish, trained in the shuttlebox apparatus to avoid shock, acquired a color discrimination between two colors (red/green) and were tested in transfer with a new set of colors (yellow/blue). Transfer color shock-pairing was either consistent with (red=yellow, blue=green) or opposite to (red $\neq$ yellow, green $\neq$ blue) categorical color coding seen in pigeons. Groups with transfer shock-pairing consistent with categorical color coding showed positive transfer, and groups with transfer shock-pairing opposite to categorical color coding showed negative transfer, similar to an attenuated reversal learning effect. These results indicate that goldfish, like pigeons, code different colors as behavioral equivalents even though they can easily learn to discriminate between them. As with pigeons, the finding of the categorical color coding phenomenon changes the conclusions drawn from earlier goldfish conditional-discrimination transfer studies using only signal color changes between acquisition and transfer testing, from evidence of concept learning to evidence for categorical color coding, on the grounds of parsimony. It is important to note that this finding affects only the explanation of conditional-discrimination transfer effects, and the fact remains that both pigeons and goldfish can learn to conditionally discriminate—pigeons for positive reinforcement, and goldfish to avoid shock.

Categorical color coding has been observed in pigeons trained by positive reinforcement procedures to conditionally discriminate between colors. Specifically, responses trained to red transfer to yellow (and vice versa) and responses to green transfer to blue (and vice versa) almost without loss (Cumming & Berryman, 1965; Zentall & Edwards, 1984; Zentall, Edwards, Moore, & Hogan, 1981). Cumming & Berryman (1965) suggested that pigeons code yellow as red and green as blue (or vice versa) and apparently treat coded pairs (e.g., red = yellow and green = blue) as equivalents. Zentall and Edwards (1984) found this to be true unless the pigeons were forced to discriminate between the two colors in a coded pair. Furthermore, categorical color coding does not appear to be restricted to red = yellow and blue = green color pairs (Zentall, Jackson-Smith, Jagielo, & Nallan, 1984). Categorical color coding restricts the interpretation of conditional discrimination transfer results: it provides a logical alternative to the conceptual learning interpretation and is more parsimonious in that it does not require the assumption of cognitive capacity.

Recently, a shock-avoidance conditional-discrimination and transfer procedure for goldfish in the shuttlebox apparatus was demonstrated (Zerbolio & Royalty, 1983). Goldfish learned to choose the matching or odd signal with two colors (red and green) and then, when tested with a new color set (blue and yellow), showed immediate positive transfer. In a second study (Zerbolio, 1984), goldfish trained with an initial color set (red and green) and extinguished with a second color set (blue and yellow)

showed transfer of extinction to the original learning colors in a relearning test. Both studies were interpreted as showing evidence for conceptual learning in goldfish. However, M. R. D'Amato (personal communication, September, 1984) has suggested that all of these transfer effects might be accounted for by a categorical color coding explanation, if goldfish categorically code colors as pigeons do.

Goldfish can be tested for categorical color coding by use of a simple discrimination paradigm. If goldfish learn to choose between two colors (e.g., red and green) to avoid shock, they can be tested in transfer with new colors (e.g., yellow and blue). In transfer, if yellow codes as red, and blue codes as green, and the shock-pairing of categorical code mates is the same (i.e., red=yellow and green=blue shock-pairing in both acquisition and transfer), positive transfer should occur. If the shock-pairing of categorical code mates is reversed between acquisition and transfer (i.e., red $\neq$ yellow and green $\neq$ blue shock-pairing in both acquisition and transfer), negative transfer, similar to a reversal learning effect, should be observed. If categorical color coding does not occur, the changed transfer test colors should represent a new discrimination problem, and all transfer performances would be expected to be independent of the specifics of color shock-pairing and to start at zero discrimination levels.

The present experiment was designed to test goldfish for categorical color coding. Since testing for categorical color coding potentially involves comparisons of positive, negative, and chance (zero) transfer performances, a simultaneous-signal presentation procedure developed for the goldfish shuttlebox apparatus was used because of its demonstrated superiority in measuring precisely these transfer effects (Zerbolio, 1985).

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METHOD

Subjects

Thirty-two 5-6 cm long goldfish, obtained from Ozark Fisheries, and housed in individual $7.5 \times 11.5 \times 12.5$ cm aquaria, served as subjects. Water in the aquaria was constantly filtered and aerated. Approximately 25% of the water was siphoned off daily and replaced in order to remove accumulated debris. Temperature ($21^\circ \pm 1^\circ\text{C}$) and pH ($7 \pm .1$) were held constant. Goldfish were fed daily.

Apparatus

Four identical $29.2 \times 11.4 \times 11.4$ cm shuttleboxes were used. A center hurdle, 6.35 cm high, with 45° sloping ramps to deeper wells in each end and a 9-cm flat top, was inserted in each shuttlebox. Water clearance at 2 cm over the hurdle top was maintained at all times. Two photocells, placed 9 cm apart, at the ends of the hurdle's flat top, served to monitor shuttling activity. Photocell light sources were 2.5-V dc prefocused penlight bulbs, operated at 1.5-V ac to extend bulb life. Light signals were provided by red, green, yellow, blue, and white 7-W, 110-V ac Christmas-tree bulbs with spectral peaks of 620 ± 4 m μ (red), 517 ± 2 m μ (green), 586 ± 2 m μ (yellow), and 474 ± 2 m μ (blue). Brightnesses, measured with a Minolta Spotmeter M, were $2.99 \pm .2$, $2.99 \pm .1$, $4.86 \pm .7$, 4.59 ± 1.1 , and 7.20 ± 1.2 mL, respectively, for the red, green, yellow, blue, and white lamps. Shock, at 7-V ac (.69 V/cm), in 200-msec pulses, was delivered via 28×10.2 cm 22-gauge stainless steel plates that lined the interior side walls of the shuttlebox. Approximately 25% of the water was siphoned off and replaced daily, which served to remove debris. Shuttleboxes were constantly aerated by end inserts, which were sandblasted and which also served to evenly diffuse color signals over the end-wall surfaces.

Procedure

All goldfish were run 40 trials a day, with a variable 60-sec interval between trials. The experiment was divided into two phases, 15 days of acquisition and 15 days of transfer testing. The inter-trial interval (ITI) was indicated by a white overhead light. Trial onset was indicated by turning off the white light, rendering the shuttlebox dark. The different color signals were not presented until the first response of the trial. A response was registered when the goldfish swam from the end of the shuttlebox occupied at trial onset across the flat top of the hurdle, through the far photobeam, and into the deep well at the other end. The 2-cm depth reduced the time spent atop the hurdle to a few seconds. The first response turned on both colors (red and green) at opposite ends of the shuttlebox. To avoid shock, the goldfish had to respond before the first scheduled shock to obtain the choice colors (one at each end), and then, depending on the colors presented, stay on the end then occupied or swim to the other end. If the end occupied following the first response displayed the safe color, and the goldfish stayed there for the remainder of the trial, no shock was administered and an avoidance was recorded. If the first response produced the shock-paired signal on the end then occupied, the goldfish had to swim to the other end, which displayed the safe signal, before the first scheduled shock to have that shock omitted. The end of the apparatus showing a specific color (red or green) was varied (Gellerman series) from trial to trial. Shocks were scheduled at 10, 12, and 13 sec following trial onset (dark), and lasted 200 msec each. At 13.2 sec after trial onset, all trial signals (dark or the color choice signals) were terminated and the white ITI light was turned on. If the goldfish failed to respond, the shuttlebox remained dark and shocks were delivered as scheduled. If a response did not occur until after the first (or second) shock, the shock-elicited response turned on the color signals, and all color shock-pairing response contingencies were in effect. Missing any one shock did not guarantee missing all shocks. The color choice (end position) of the goldfish was tested at each of the scheduled shock times, and depending on the goldfish's color choice (end position), shock was delivered

as scheduled. An avoidance was not recorded on a given trial unless the goldfish missed all three shocks. Except for changes in signal colors, these procedures and contingencies were in effect throughout both the acquisition and transfer testing phases.

In acquisition, half ($n=16$) received red/green (R/G) color choice signals, and half ($n=16$) received blue/yellow (B/Y) color signals. The 16 goldfish for each color set were further divided, with half ($n=8$) receiving one signal/shock-pairing arrangement, and the other half ($n=8$) receiving the other shock-pairing arrangement. This generated the factorial pairing of two signal color sets (R/G, B/Y) $\times$ two balanced shock-pairing arrangements [shock (–), shock-omission (+)], and produced four different groups with 8 goldfish in each (R+/G–, R–/G+, B+/Y–, B–/Y+). All groups were run for 15 days with these signal/shock-pairing arrangements.

In transfer, all goldfish had both of their signal colors changed. Those with red/green colors in acquisition were tested in transfer with blue/yellow colors (R/G to B/Y), and those with blue/yellow in acquisition had red/green in transfer (B/Y to R/G). The critical manipulation was the shock-pairing of the changed signal colors in transfer. The shock-pairing of the changed color signals was either consistent with categorically coded color pairs (R=Y, G=B) or opposite to the categorical color pair coding (R $\neq$ Y, G $\neq$ B). To accomplish this, each of the four acquisition color $\times$ shock-pairing groups was split into matched (on acquisition performance) halves ($n=4$). Half received signal/shock-pairing in transfer consistent with categorical color coding and half received signal/shock-pairing in transfer opposite to categorical color coding [e.g., R+/G– ($n=8$) to Y+/B– ($n=4$), Y–/B+ ($n=4$)]. This generated eight transfer test groups of 4 goldfish each, half (four groups of 4 each) with transfer signal/shock-pairing consistent with categorical color coding in pigeons, and half (four groups of 4 each) with transfer signal/shock-pairing opposite to categorical color coding in pigeons, and constituted a factorial arrangement with factors acquisition color sets (2), acquisition shock-pairing (2), and consistent/opposite coded pair shock-pairing in acquisition/transfer (2). All goldfish were tested for 15 days in transfer with their changed signal color and shock-pairing arrangements.

Two measures were recorded daily for each goldfish: the number of trials with response before shock (TwR), and the number of trials where no shocks were administered (avoidances). An avoidance (designated as S+) could occur only if the goldfish responded before shock and, via appropriate responses, occupied the end displaying the shock-omission-paired signal at each of the three scheduled shock times. If the goldfish responded before shock, but at one or more of the scheduled shock times occupied the end showing the shock-pairing signal, shock was delivered as scheduled and was designated as S–. Since S+ and S– represented choices of the safe (S+) or shock-paired (S–) signals, a discrimination index (DI) measure was calculated daily for each goldfish. The DI is defined as $[(S+) - (S-)]/40$, where $(S+) + (S-) = \text{TwR}$, and where 40 is the number of daily trials. The DI has limits of ± 1.00 . cursory examination reveals that the DI measure reflects the requirement of an initial response, differentiates between discriminated and random choice behavior, and distinguishes between goldfish responding on a few versus many trials. Furthermore, since DI can be positive (S+ preference), negative (S– preference), or zero (random or chance preference), it allows convenient comparisons of positive, negative, and chance transfer performances. Other response measures, such as ITI response rates, were not found to be informative in this and earlier studies, and were omitted.

RESULTS

The results of the 15-day acquisition and 15-day transfer testing phases were combined into two sets of five 3-day blocks and separated to facilitate statistical analysis and presentation. Statistical analyses on both the 15-day and five 3-day block measures were completed but

differed in no important detail; therefore, except as noted, only the five 3-day block results and analyses are presented. Figure 1 shows the TwR, avoidance, and DI measures for both acquisition and transfer testing in five 3-day blocks.

The left half of Figure 1 shows the original-learning results. All goldfish showed, over days of acquisition training, an increasing proportion of trials with response (TwR), number of avoidances, and choice of (or end displaying) the shock-omission paired color signal. No differences due to differences in signal colors (R/G, B/Y) or color shock-pairing arrangements were observed. These impressions were confirmed by the analyses. Significant TwR increases with training over blocks [$F(4,120) = 87.39, p < .01$], increases in avoidances [$F(4,120) = 325.27, p < .01$], and increases in DI or discriminative choice of the safe (shock-omission) signal [$F(4,120) = 297.21, p < .01$] were observed. No other significant effects or interactions in any of the acquisition analyses were observed.

Figure 1. Mean percent trials with response (TwR), avoidances, and mean discrimination indexes (DI) for the five 3-day blocks of original learning (acquisition) and transfer testing. On the avoidance and DI measures, differences between groups with color shock-pairing consistent with ($R=Y, G=B$) and opposite to ($R \neq Y, B \neq G$) categorical color coding are indicated. No differences were observed on the TwR measures. Chance (from zero) discrimination is indicated on the DI measure.

The right half of Figure 1 shows the transfer test results. TwR performances remained high for all groups throughout transfer testing. On the avoidance and DI measures, groups tested with transfer signal shock-pairing consistent with categorical color coding ($R=Y, G=B$) immediately chose the new color signal paired with shock omission, and thus showed significant positive transfer. Groups tested with transfer signal shock-pairing opposite to categorical color coding ($R \neq Y, G \neq B$) showed significant drops in avoidance and DI performance, to chance or zero discrimination levels, but with additional transfer training all $R \neq Y$ and $G \neq B$ groups relearned the discrimination with the new transfer colors. All of these impressions were confirmed by the statistical analyses. No differences of any sort were observed in the TwR analysis. For the avoidance measure, significant effects were observed for consistent/opposite to categorical code shock-pairing [$F(1,30) = 10.10, p < .01$], testing over five 3-day blocks [$F(4,120) = 44.51, p < .01$], and shock-pairing $\times$ blocks of training interaction [$F(4,120) = 14.50, p < .01$]. A partition of the interaction found the groups with shock-pairing opposite to categorical color coding showing significantly fewer avoidances than groups with shock-pairing consistent with categorical color coding on the first and second blocks of transfer testing, but not thereafter [$F(1,150) = 74.62, p < .01$ for the first block, $F(1,150) = 6.25, p < .05$ for the second block]. Comparable main effects were found for the DI measure, including the interaction. A partition of the consistent versus opposite shock-pairing $\times$ blocks of training interaction on the DI measure found opposite-code shock-paired groups demonstrating significantly poorer discrimination performance on the first [$F(1,150) = 76.66, p < .01$] and second [$F(1,150) = 6.85, p > .05$] blocks, but not thereafter. Furthermore, as shown in the lower right panel of Figure 1, it is clear that the groups with shock-pairing consistent with categorical coding continued to discriminate at DI levels well above chance, whereas groups with shock-pairing opposite to categorical coding dropped to chance levels of discrimination.

While it is clear that groups with transfer shock-pairing consistent with categorical color coding showed significant positive transfer, the groups with transfer shock-pairing opposite to categorical color coding did not show the expected significant negative transfer or reversal effect. However, the reversal effect would be expected to occur early in transfer testing. Since the blocking of the first 3 days in transfer might have masked the reversal effect, an additional analysis on the DI measure for the first 3 days of transfer was completed. Figure 2 shows these results.

Figure 2 clearly shows that the groups with shock-pairing opposite to categorical color coding ($R \neq Y, G \neq B$) dropped in DI performance below chance discrimination levels on the first day of transfer testing, confirming the expected early reversal effect. The last 3 days of acquisition are shown for comparison only. The analysis of the

Figure 2. Differences in mean DI performances for the first 3 days of transfer testing (16, 17, and 18) for groups with color shock-pairing consistent with ($R=Y$, $B=G$) and opposite to ($R \neq Y$, $B \neq G$) categorical color coding. A chance discrimination envelope for positive and negative transfer effects is incorporated in the figure. The last 3 days (13, 14, and 15) of acquisition training are shown for comparative purposes.

DI results found significant effects for consistent/opposite shock-pairing, days of testing, and a consistent/opposite $\times$ days interaction. The partition of this interaction found opposite shock-paired groups discriminating well below consistent shock-paired groups for each of the first 3 days [$F_s(1,90) = 75.80, 23.72$, and 13.87 , respectively, for Days 1, 2, and 3, all $p_s < .01$]. Comparable results (not shown) were found on the avoidance measure.

DISCUSSION

The results of the present study show quite clearly that goldfish, like pigeons, categorically code colors. Specifically, goldfish trained to discriminate between red and green and tested in transfer with blue and yellow (or vice versa) show positive transfer when categorical code mates are identically shock-paired in acquisition and transfer testing (red=yellow, green=blue), and negative transfer when categorical code mates are paired differently (red $\neq$ yellow, green $\neq$ blue) in acquisition and transfer testing.

It is tempting to conclude that the basis for the categorical coding in goldfish rests on a simple generalization mechanism. However, this seems unlikely for several reasons. First, earlier work shows that goldfish, like pigeons, learn easily to discriminate between red and yellow and between blue and green color signals (Zerbolio, 1981). Second, when categorical color code mates are not identically shock-paired in acquisition and transfer, a simple generalization model would predict negative transfer effects comparable to a reversal learning effect. Goldfish with categorical color code mates paired differently in acquisition and transfer recover avoidance discrimination much faster (see Figure 2) than goldfish with color shock-

pairing reversed in transfer testing (see Zerbolio, 1981). Finally, work with pigeons implies that the categorical coding process can be quite arbitrary (Zentall & Edwards, 1984; Zentall, Jackson-Smith, Jagielo, & Nallan, 1984). Since the categorical color coding phenomenon in goldfish appears comparable to that observed in pigeons, it is possible that the goldfish phenomenon may be just as arbitrary.

Finding a categorical color coding phenomenon in goldfish produces as much restriction on the explanations of conditional discrimination transfer effects in goldfish as it does in pigeons. Specifically, all transfer effects in conditional discrimination designs employing only color changes in transfer testing can be more parsimoniously explained by the categorical color coding phenomenon than by the conceptual learning process. Since Zerbolio & Royalty (1983) and Zerbolio (1984) used changed color signals in their transfer test situations, it is clear that none of their transfer results can be interpreted as supporting a conceptual learning process. At best, they support only the categorical color coding phenomenon.

Since the categorical color coding phenomenon invalidates concept-learning conclusions in studies using color-change signals, some researchers have turned to the use of different symbols, as well as different color signals (Zentall & Edwards, 1984). Comparable work with goldfish is currently under way in our labs.

It is important to recognize that the discovery of a categorical color coding phenomenon in both goldfish and pigeons affects only the explanations of the *transfer effects* of conditional-discrimination experiments. It does not alter the fact that both pigeons and goldfish are able to learn matching and oddity conditional discriminations. The major difference is that pigeons learn conditional discriminations with positive reinforcement procedures, whereas goldfish learn comparable conditional discriminations with negative reinforcement procedures (to avoid shock).

The positive aspect of these results is that the categorical color coding phenomenon occurs in two species as phylogenetically disparate as goldfish and pigeons. This suggests substantial similarities between the color-vision processes of these two species at least, and, coupled with the fact that both are able to learn color-signal conditional discriminations, perhaps similarities in other physiological and learning processes as well. Certainly these results support the notion that the basic processes controlling phenomena associated with sensory input and learning are independent of phyletic level.

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